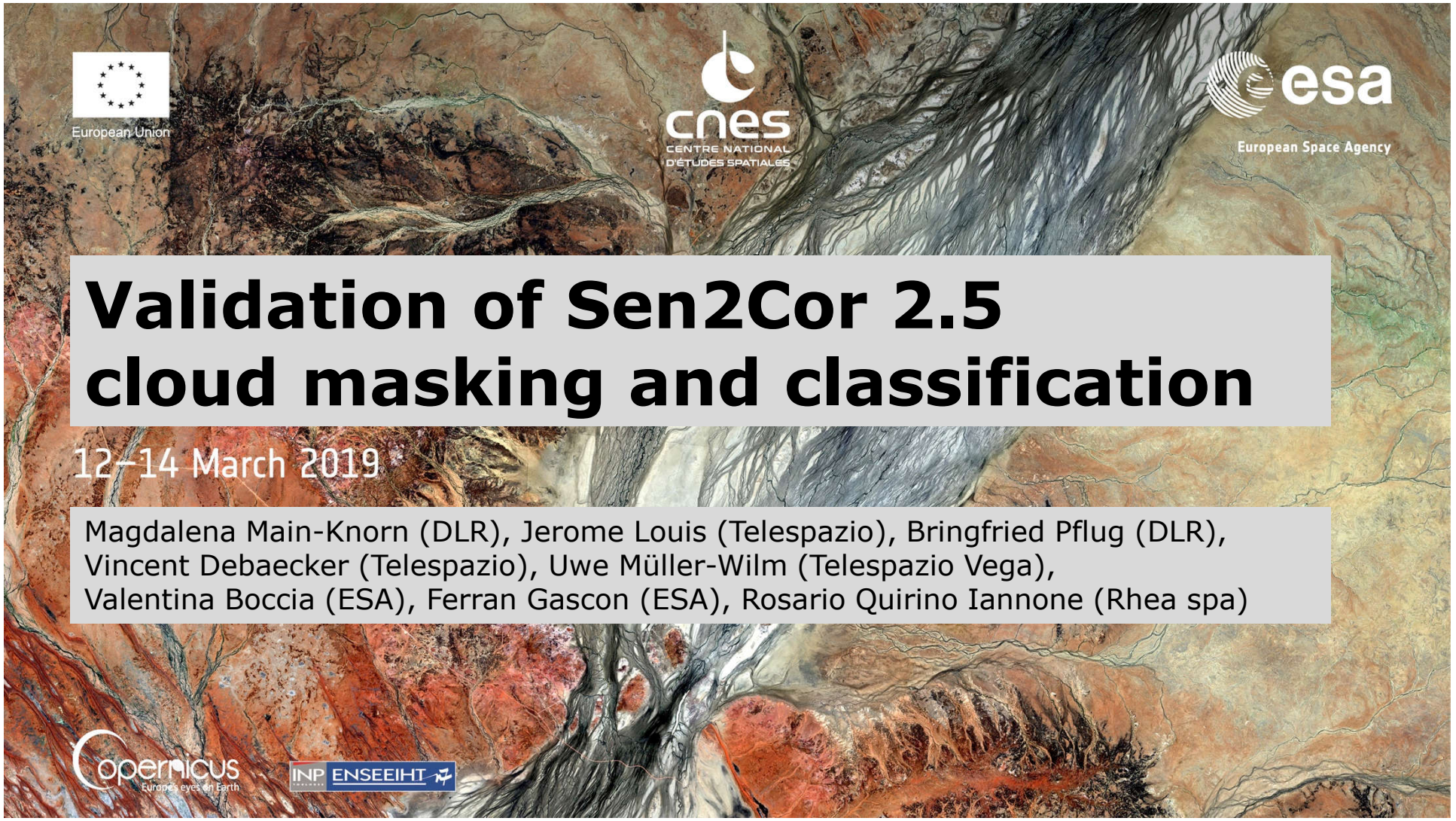
European Union
cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES
esa
European Space Agency
Validation of Sen2Cor 2.5 cloud masking and classification
12–14 March 2019
Magdalena Main-Knorn (DLR), Jerome Louis (Telespazio), Bringfried Pflug (DLR),
Vincent Debaecker (Telespazio), Uwe Müller-Wilm (Telespazio Vega),
Valentina Boccia (ESA), Ferran Gascon (ESA), Rosario Quirino Iannone (Rhea spa)
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Europe's eyes on Earth
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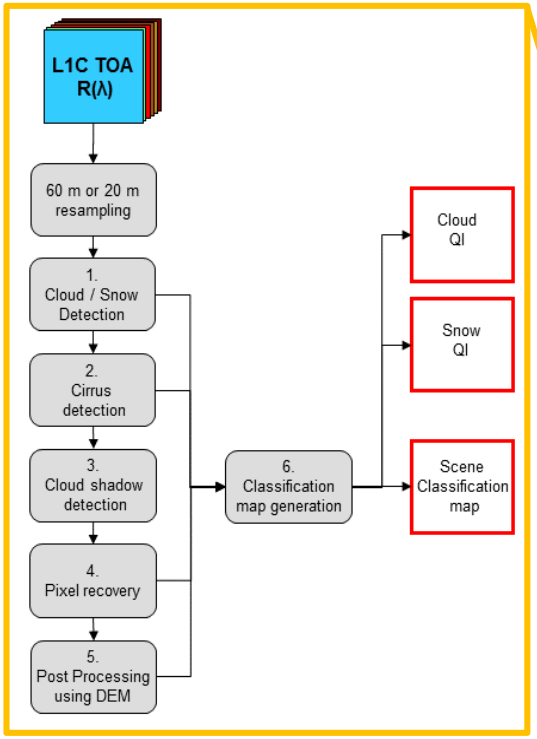
Outline

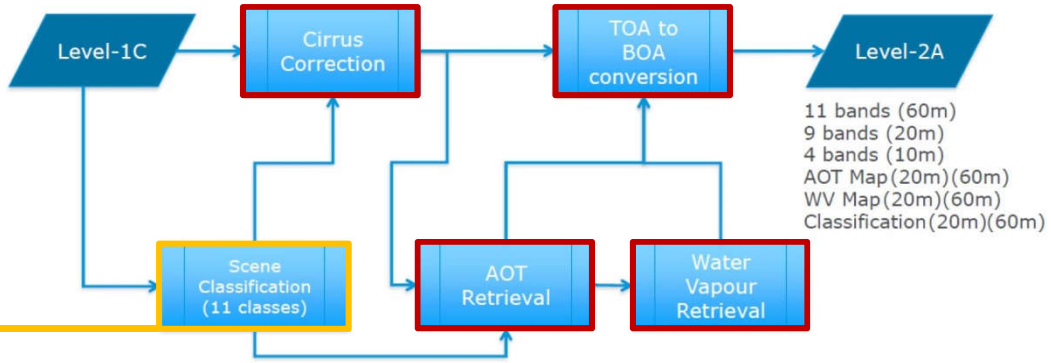
1. Sen2Cor Processor
2. Validation Dataset
3. Validation Procedure
4. Results and Examples
5. Conclusions
6. Outlook

# 1. Sen2Cor 2.5 Processor

- Atmospheric correction processor, developed by Telespazio on behalf of ESA
- Mono-temporal processor: corrects single-date Sentinel-2 L1C Top-Of-Atmosphere (TOA) products from the effects of the atmosphere and delivers a L2A Bottom-Of-Atmosphere (BOA) surface reflectance product
- Additional outputs: Aerosol Optical Thickness (AOT) map, Water Vapour (WV) map and Scene Classification (SCL) map with Quality Indicators for cloud and snow probabilities, in JPEG 2000 image format
- L2A data production run on the global systematic basis with dissemination through the Copernicus Open Access Hub since December 2018
- Processor can be freely downloaded (latest release 2.5) and used for processing L1C images

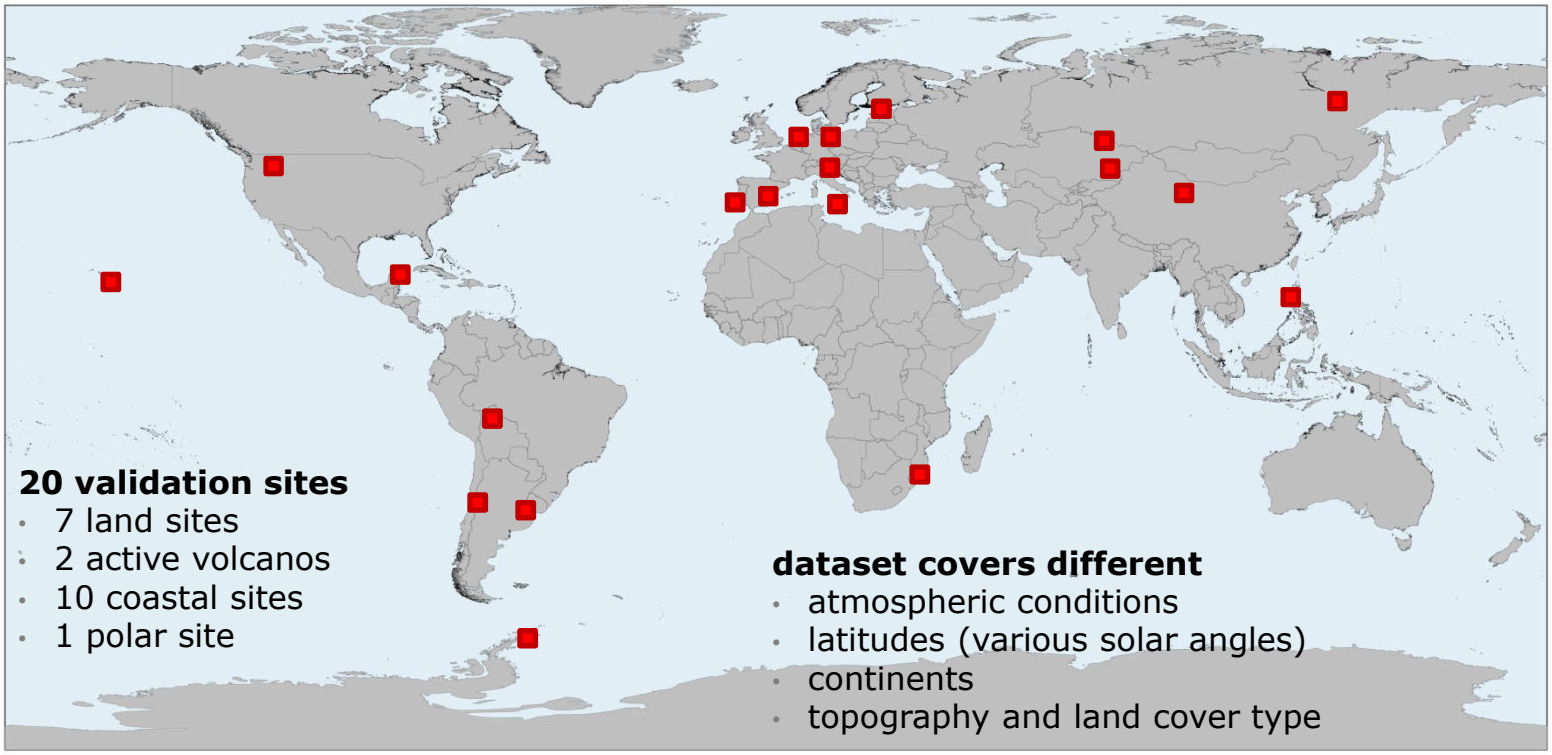
# 1. Sen2Cor 2.5 Processor Framework - Scene Classification Module (SCL)




- Two main modules: Scene Classification (SCL), Atmospheric Correction (AC)
- DEM downloaded automatically by the processor (SRTM) or provided by the user in DTED format
- SCL is mainly based on a series of threshold tests on L1C spectral bands, band ratios and indices
- ESA CCI auxiliary data support for water and snow detection

# 2. Validation Dataset



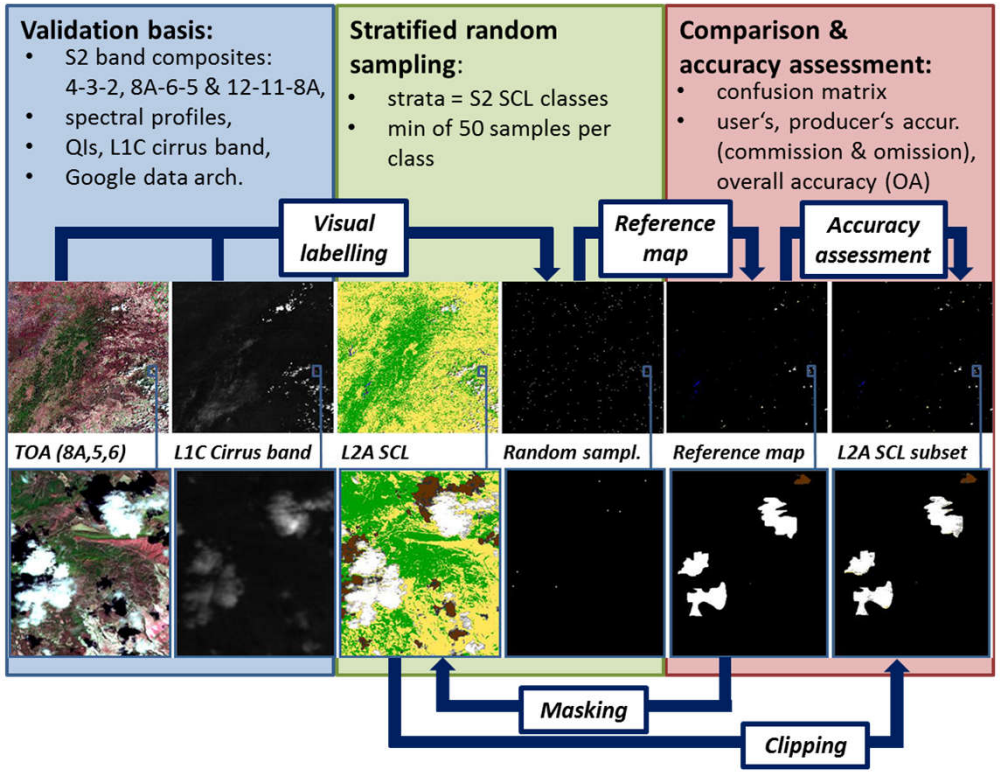
**20 validation sites**
- 7 land sites
- 2 active volcanos
- 10 coastal sites
- 1 polar site

**dataset covers different**
- atmospheric conditions
- latitudes (various solar angles)
- continents
- topography and land cover type

# 2. Validation Dataset

| Country | Site | Tile | Date | L1C clouds | Land cover | Special features |
|---|---|---|---|---|---|---|
| Antarctic | Antarctic | 21EVK | 04.02.2016 | 9,91 | snow, ice, water | clouds over snow, clouds and shadows over water |
| Argentina | Casleo | 19HDE | 12.08.2016 | 21,73 | snow, rural, mountains | transparent clouds, cloud shadows, topo shadows |
| Argentina | Buenos Aires | 21HUC | 27.08.2018 | 0,00 | urban, rural, water | sediment in water, very bright objects |
| Bolivia | Puerto Siles | 19LHF | 06.09.2018 | 0,00 | rural, vegetation, water | different water color and sediment, bright soil |
| China | Dunhuang | 46TFK | 22.01.2018 | 24,14 | snow, rural, desert | no clouds, solar panels, |
| Estonia | Tallin | 35VLG | 14.07.2018 | 2,09 | urban, rural, water | algal bloom, bright objects |
| Germany | Berlin | 33UUU | 04.05.2018 | 0,87 | urban, rural, water | asparagus fields |
| Italy | Etna Volcano | 33SVB | 09.03.2017 | 6,86 | snow, rural, urban, water | active volcano, burning and burned area, ash cloud |
| Italy | Venice | 32TQR | 16.09.2018 | 2,42 | coast, industry, urban, rural, water | black coastline, topographic shadows, bright object |
| Kazakhstan | Pavlodar | 43UET | 26.07.2018 | 0,13 | rural, industrial and natural water | different water colours, |
| Kazakhstan | Balkhash | 43TFM | 30.07.2018 | 7,18 | water, rural | black coastal line |
| Mexico | Cancun | 16QDJ | 27.05.2018 | 6,68 | rural, vegetation, water | waves, sediment, algas(?), clouds |
| Mosambique | Maputo | 36JVS | 13.07.2018 | 0,00 | rural, urban, water | burned area, sediment in water, |
| Netherlands | Amsterdam | 31UFU | 13.09.2018 | 4,73 | rural, urban, vegetation, water | black coastline, clouds & cloud shadows over water |
| Phillipines | Manila | 51PTS | 19.03.2018 | 1,44 | urban, rural, water | sediment / aquacultures, very bright objects, |
| Portugal | Lagos | 29SNB | 08.08.2018 | 0,00 | rural, water | waves, sediment, burned area, bright objects |
| Russia | Yakutsk | 52VEP | 08.03.2016 | 61,53 | snow, rural | transparent clouds |
| Spain | Barrax | 30SWH | 09.05.2017 | 17,67 | rural, vegetation, mountains | cumulus and cirrus clouds |
| Spain | Barrax | 30SWH | 19.05.2017 | 1,64 | rural, vegetation, mountains | cumulus clouds |
| USA | Rimrock | 11TMM | 12.05.2018 | 0,74 | snow, rural, urban, water | very bright objects |
| USA-Hawaii | Kilauea Volcano | 05QKB | 23.04.2018 | 28,41 | rural, water | active volcano, burning and burned area, ash cloud |

# 3. Validation Procedure




Statistical metrics:

**Overall accuracy (OA)**

*Percentage of correctly classified pixels.*

**Omission error (OE) ; Producer Accuracy (PA)**

*The share of reference pixels in that class that have been "omitted" in the classification image.*

*OE [%] = 100 - Producer Accuracy*

**Commission error (CE) ; User Accuracy (UA)**

*Percentage of class pixels in the classification image which are falsely classified.*

*CE [%] = 100 - User Accuracy*

Statistics are calculated for:

- All classes (original SCL product)
- Valid pixels (over land and water) separation
- Clouds (medium- and high probability clouds, cirrus) separation

# 3. Validation Procedure - Limitations

- Stratified random sampling is based on classification SCL (class = strata) - it can bias validation results, where Sen2Cor classification failed
- Reference samples set is inbalanced, semi-proportional to the class area
- Definition of thin cirrus and visual interpretation of clouds is subjective & challenging
- Internal test on the subjectivity of the validation method (4 validating persons, 2 products) revealed quite stable results (st.dev of classification accuracy ~5-6%). More extended tests are required.
- In preparation classification validation protocol for L2A to assure validation quality and comparability between algorithms

# 4. Results – per site

| Country | Site | Tile | Date | L1C clouds | OA | OA valid | OA clouds | Pixel validated |
|---|---|---|---|---|---|---|---|---|
| Antarctic | **Antarctic** | 21EVK | 04.02.2016 | 9,91 | 94,7 | 96,8 | 98,8 | 527803 |
| Argentina | **Casleo** | 19HDE | 12.08.2016 | 21,73 | 63,8 | 86,1 | 98,1 | 186238 |
| Argentina | **Buenos Aires** | 21HUC | 27.08.2018 | 0,00 | 91,8 | 97,3 | no clouds | 31841 |
| Bolivia | **Puerto Siles** | 19LHF | 06.09.2018 | 0,00 | 91,1 | 94,9 | 94,8 | 80580 |
| China | **Dunhuang** | 46TFK | 22.01.2018 | 24,14 | 57,3 | 66,2 | no clouds | 105454 |
| Estonia | **Tallin** | 35VLG | 14.07.2018 | 2,09 | 84,3 | 90,4 | 95,6 | 71773 |
| Germany | **Berlin** | 33UUU | 04.05.2018 | 0,87 | 93,4 | 96,5 | no clouds | 51964 |
| Italy | **Etna Volcano** | 33SVB | 09.03.2017 | 6,86 | 95,8 | 97,9 | 99,4 | 132340 |
| Italy | **Venice** | 32TQR | 16.09.2018 | 2,42 | 80,3 | 91,0 | 89,0 | 103780 |
| Kazakhstan | **Pavlodar** | 43UET | 26.07.2018 | 0,13 | 70,1 | 82,6 | 83,2 | 90803 |
| Kazakhstan | **Balkhash** | 43TFM | 30.07.2018 | 7,18 | 77,4 | 93,7 | 95,7 | 94578 |
| Mexico | **Cancun** | 16QDJ | 27.05.2018 | 6,68 | 90,5 | 93,8 | 95,2 | 32082 |
| Mosambique | **Maputo** | 36JVS | 13.07.2018 | 0,00 | 80,5 | 85,1 | 82,5 | 90043 |
| Netherlands | **Amsterdam** | 31UFU | 13.09.2018 | 4,73 | 71,1 | 81,5 | 88,7 | 100018 |
| Phillipines | **Manila** | 51PTS | 19.03.2018 | 1,44 | 82,1 | 90,0 | 91,6 | 106263 |
| Portugal | **Lagos** | 29SNB | 08.08.2018 | 0,00 | 96,8 | 97,3 | no clouds | 69753 |
| Russia | **Yakutsk** | 52VEP | 08.03.2016 | 61,53 | 69,9 | 93,8 | 92,9 | 177983 |
| Spain | **Barrax** | 30SWH | 09.05.2017 | 17,67 | 64,6 | 96,9 | 98,7 | 141546 |
| Spain | **Barrax** | 30SWH | 19.05.2017 | 1,64 | 90,5 | 98,7 | 99,5 | 104799 |
| USA | **Rimrock** | 11TMM | 12.05.2018 | 0,74 | 90,2 | 98,2 | 99,2 | 103394 |
| USA-Hawaii | **Kilauea Volcano** | 05QKB | 23.04.2018 | 28,41 | 60,4 | 75,4 | 74,2 | 118357 |
| | | | | **Average OA:** | **80,9** | **Averaged ref per SCL:** | | **120066** |
| | | | | | | **Total validated pixels:** | | **2521392** |

**Best case:**
**OA > 90%;**
**OA clear pixels > 94%**
**OA clouds > 95%**

**Moderate case:**
**OA 70-85%;**
**OA clear pixels 80-94%**
**OA clouds 80-96%**

**Poor case:**
**OA >= 64 %**
**but**
**OA clear pixels > 86%**
**OA clouds > 93%**

**The worst case:**
**OA <= 60%;**
**OA clear pixels &**
**OA clouds < 75%**

# 4. Results – per valid and cloudy pixels

| Valid pixels over land and water | | | | |
|---|---|---|---|---|
| | **Land-Water** | **Others** | **Sum** | **Commission error** |
| **Valid pixels Land-Water** | 1119112 | 137273 | 1256385 | **10.9** |
| **Others** | 83033 | 1181974 | 1265007 | **6.6** |
| **Sum** | 1202145 | 1319247 | 2521392 | |
| **Omission error** | **6.9** | **10.4** | | |
| **All clouds** | | | | |
| | **Clouds** | **Others** | **Sum** | **Commission error** |
| **Clouds** | 577133 | 34464 | 611597 | **5.6** |
| **Others** | 114256 | 1795539 | 1909795 | **6.0** |
| **Sum** | 691389 | 1830003 | 2521392 | |
| **Omission error** | **16.5** | **1.9** | | |

(+) Good performance for valid pixels detection (CE=10,9%; OE=6,9%)

(–) High omission error for clouds detection (CE=5,6%; OE=16,5%)

- Increased CE for valid pixels means that too many invalid pixels (mainy clouds) were classified as valid
- High OE for clouds means that too many clouds were classified as valid pixels (mainly on the cloud borders)
- At this Sen2Cor evolution stage dilation of cloud mask would not decrease cloud omission error !!

# 4. Results – per selected classes

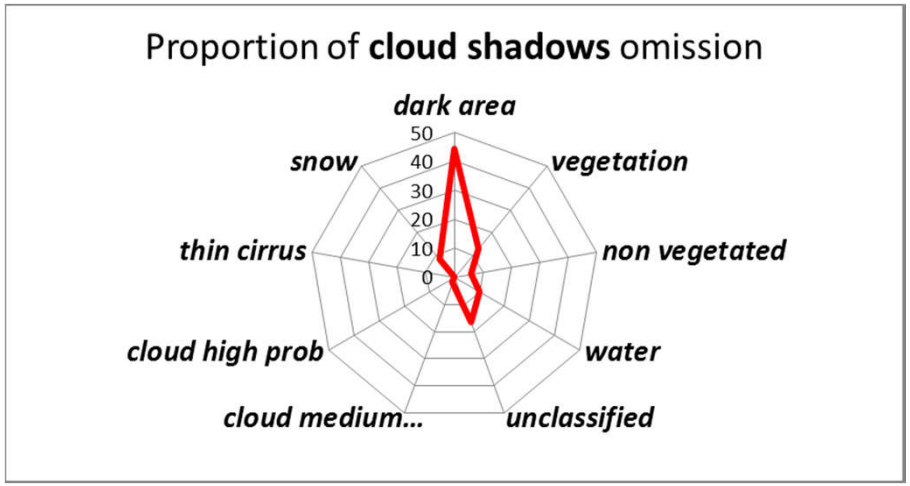
| Class | Commission error | Omission error |
|---|---|---|
| **Cloud shadows** | 4,5 | 55,6 |
| **Vegetation** | 17,7 | 0,5 |
| **Non vegetated** | 16,1 | 16,7 |
| **Water** | 5,6 | 1,9 |
| **Snow** | 5,5 | 10,3 |

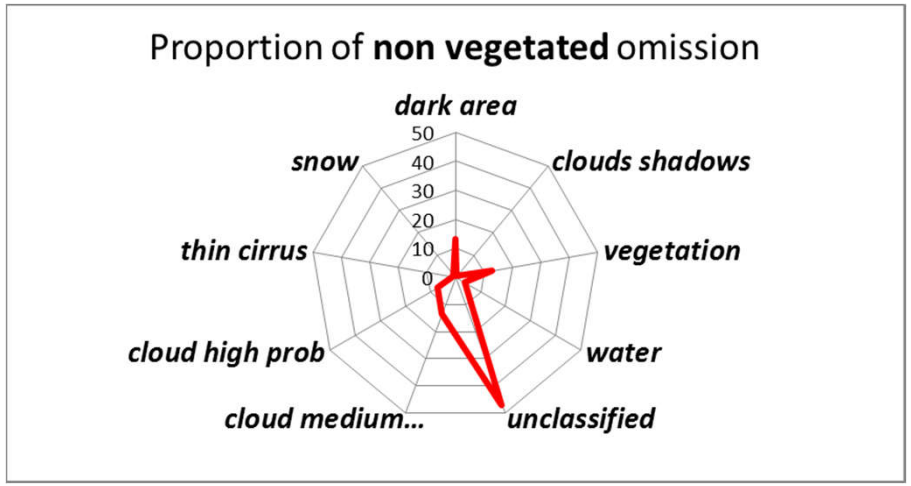
(+) Very low omission for vegetation and water

(+) Very low commission for cloud shadows, water and snow/ice

(–) Very high omission for cloud shadows

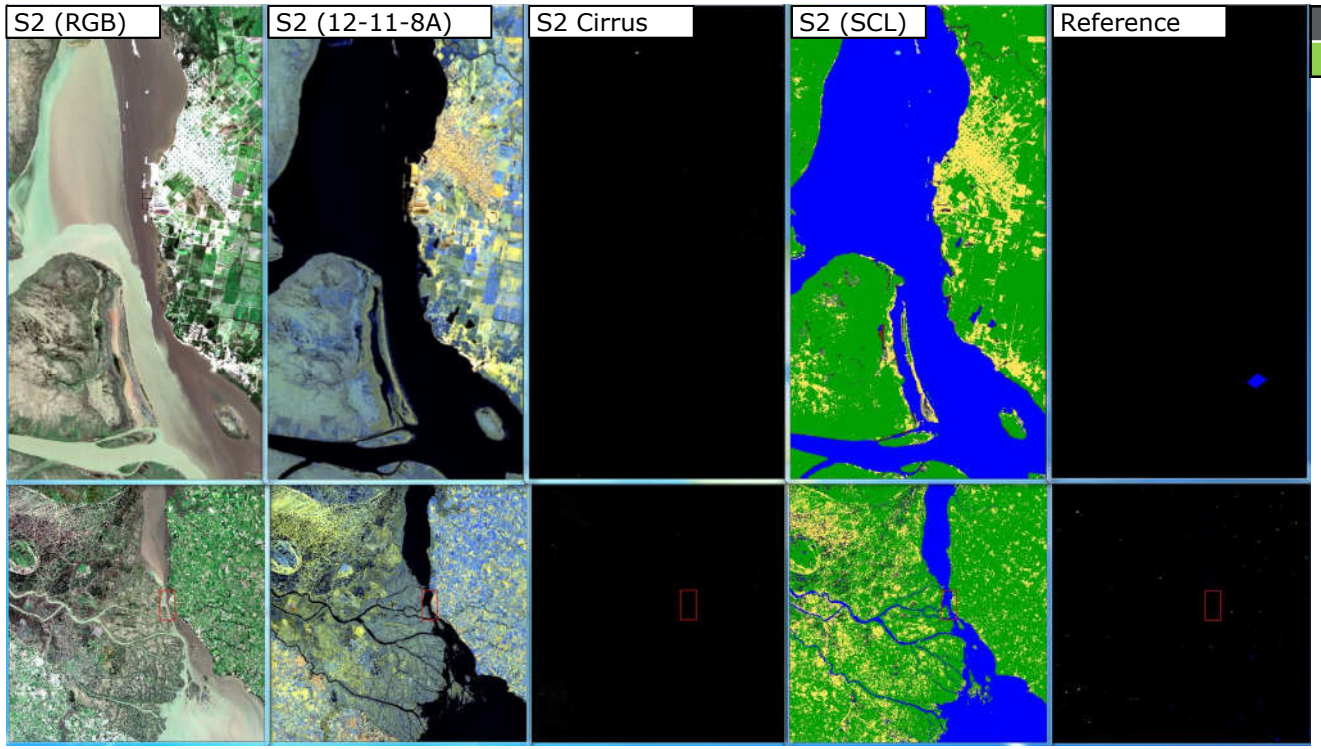
(–) Higher omission for non-vegetated pixels



# 4. Results/ Example 1: Buenos Aires

## – urban area, sediment in water




| OA | OA valid | OA clouds |
|---|---|---|
| 91,8 | 97,3 | no clouds |

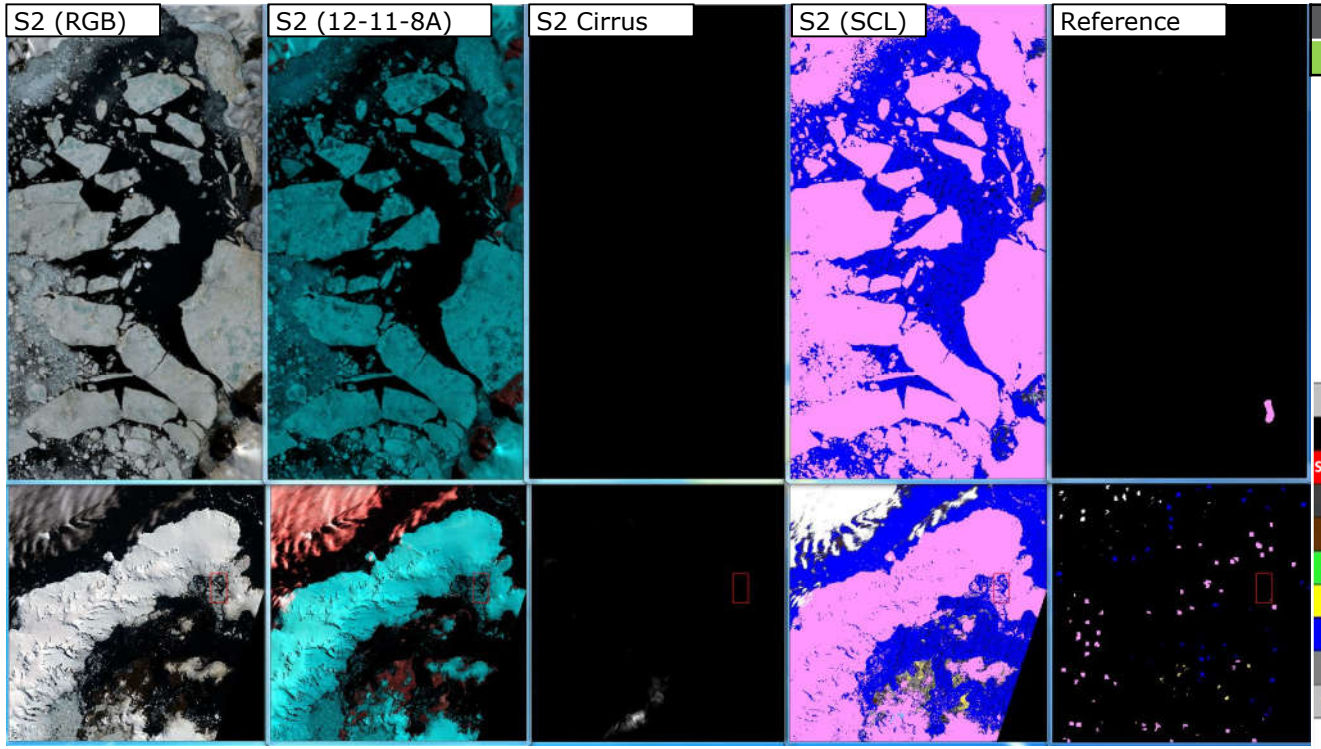
(+) Different water colors and ship traffic possible to identify (but it is not the focus of SCL classification)

(+) Water, vegetation and non vegetated recognized correctly (also on bright urban surfaces)

| Class |
|---|
| NO_DATA |
| SATURATED_or_DEFECTIVE |
| DARK_AREA_PIXELS |
| CLOUD_SHADOWS |
| VEGETATION |
| NON_VEGETATED |
| WATER |
| UNCLASSIFIED |
| CLOUD_MEDIUM_PROBAB |
| CLOUD_HIGH_PROBAB |
| THIN_CIRRUS |
| SNOW |

# 4. Results/ Example 2: Antarctic

## – snow, ice, clouds



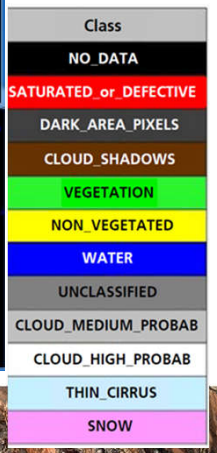

S2A_USER_PRD_MSIL2A_PDMC_20160206T015135_R095_V20160204T131909_20160204T131909.SAFE

| OA | OA valid | OA clouds |
|---|---|---|
| 94,7 | 96,8 | 98,8 |

(+) Clouds over water and snow classified properly

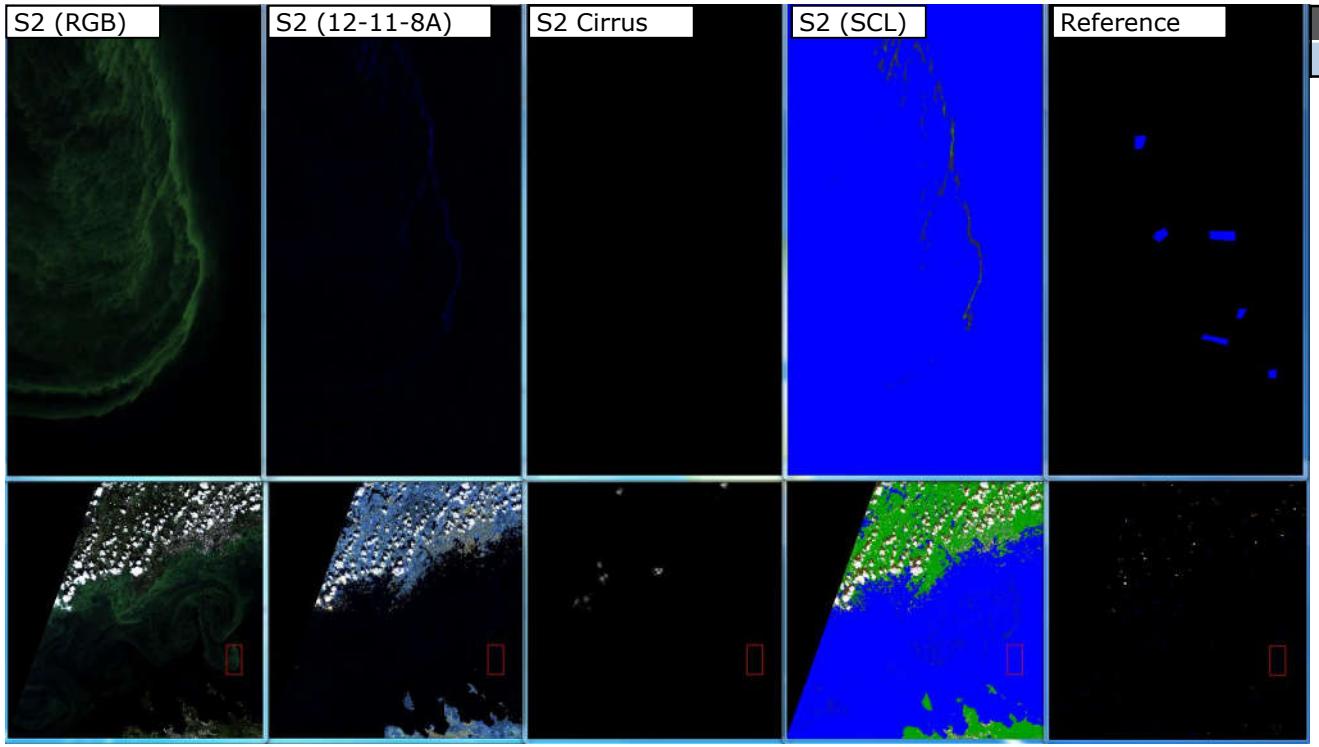
(+) Water, snow and ice classified correctly

(–) Omission of non vegetated towards clouds



# 4. Results/ Example 3: Tallin

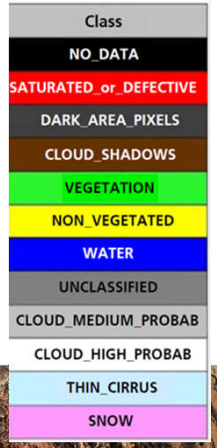
## – algal bloom, urban




| OA | OA valid | OA clouds |
|---|---|---|
| 84,3 | 90,4 | 95,6 |

(+) Cloud, vegetation and water classified properly

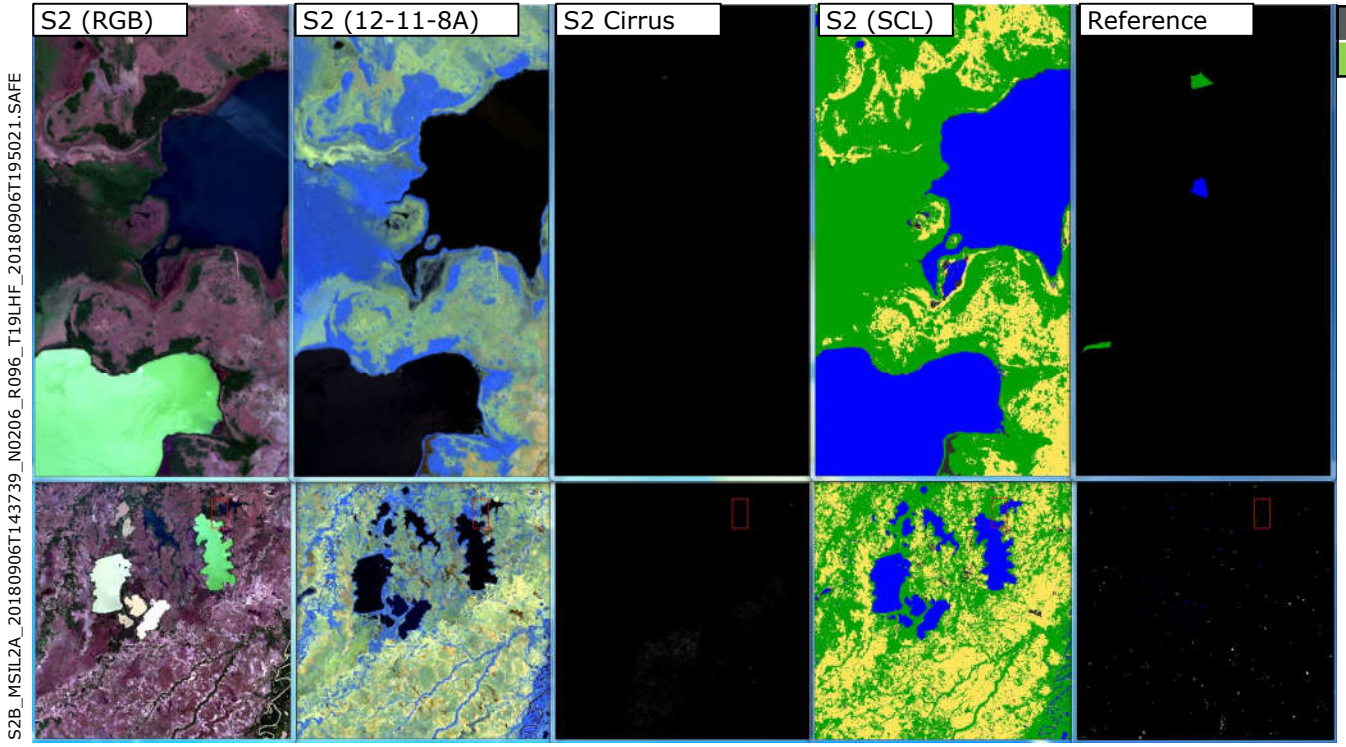
(+) Algal bloom possible to identify (but it is not the focus of SCL classification)




(–) Lower OA of clear pixels due to misclassification of bright harbor area as clouds

# 4. Results/ Example 4: Puerto Siles

## – water colors, sunglint




| OA | OA valid | OA clouds |
|---|---|---|
| 91,1 | 94,9 | 94,8 |

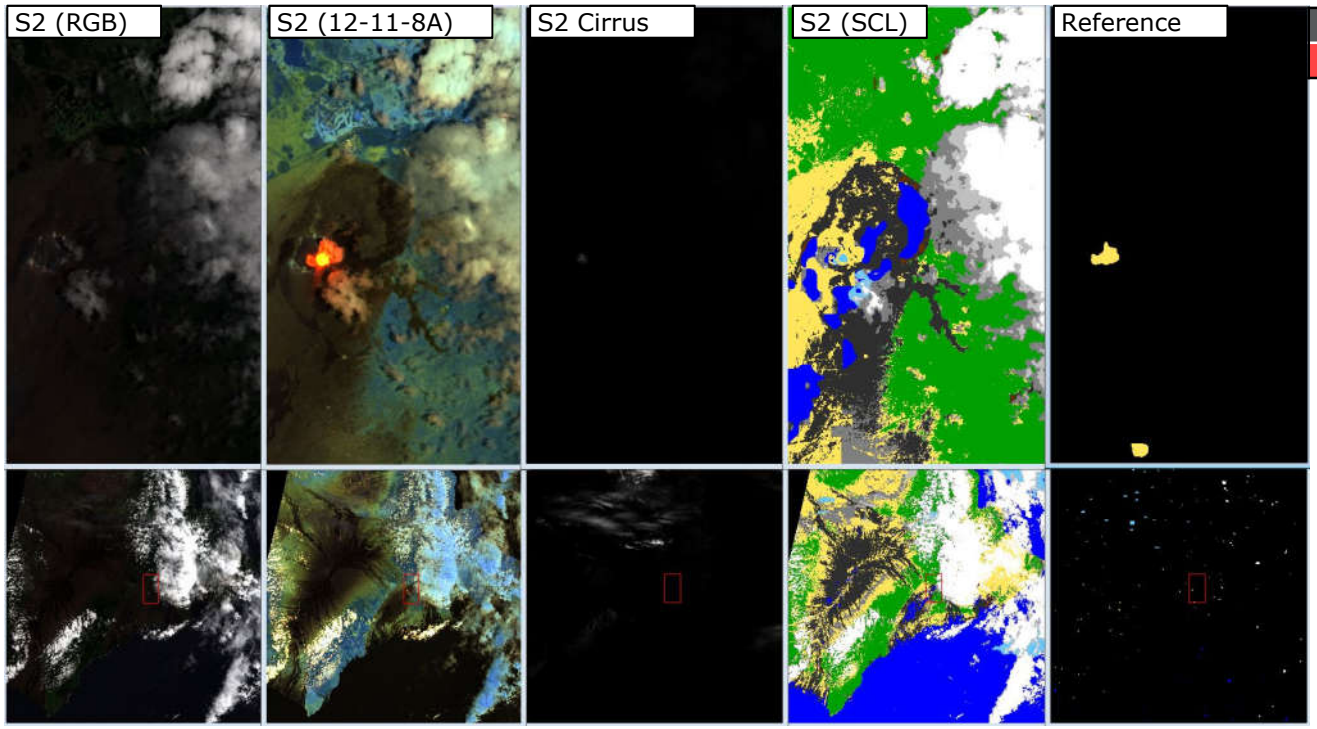
(+) Water classified properly despite of different water colors

(+) Vegetation and non vegetated recognized correctly

| Class |
|---|
| NO_DATA |
| SATURATED_or_DEFECTIVE |
| DARK_AREA_PIXELS |
| CLOUD_SHADOWS |
| VEGETATION |
| NON_VEGETATED |
| WATER |
| UNCLASSIFIED |
| CLOUD_MEDIUM_PROBAB |
| CLOUD_HIGH_PROBAB |
| THIN_CIRRUS |
| SNOW |

# 4. Results/ Example 5: Kilauea Volcano

## – fire, burned area, clouds, smoke




| OA | OA valid | OA clouds |
|---|---|---|
| 60,4 | 75,4 | 74,2 |

(+) Cloud, vegetation & non vegetation classified properly

(+) Fire and burned area partially recognized; burned area classified as dark area

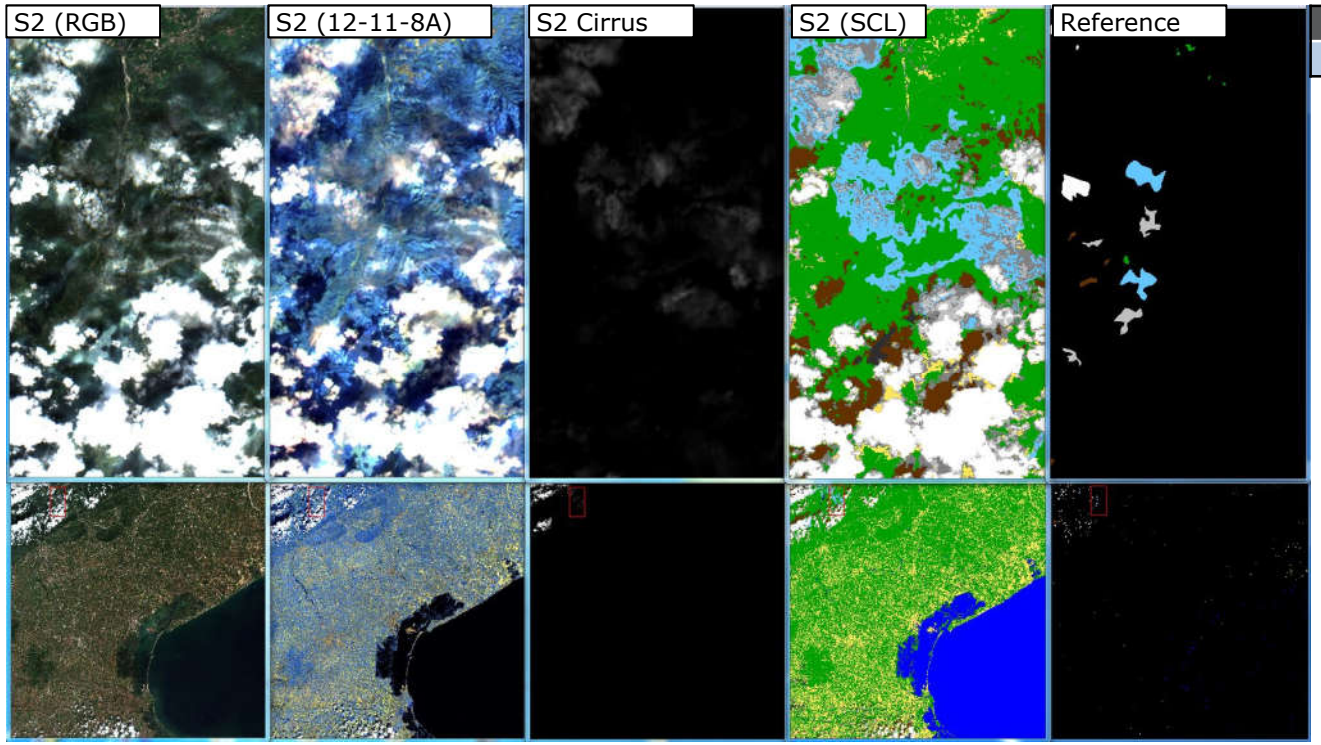
| Class |
|---|
| NO_DATA |
| SATURATED_or_DEFECTIVE |
| DARK_AREA_PIXELS |
| CLOUD_SHADOWS |
| VEGETATION |
| NON_VEGETATED |
| WATER |
| UNCLASSIFIED |
| CLOUD_MEDIUM_PROBAB |
| CLOUD_HIGH_PROBAB |
| THIN_CIRRUS |
| SNOW |

(–) Commission of water around volcano

(–) Unclear treatment of haze or smoke (no class defined)

# 4. Results/ Example 6: Venice

## – clouds and cirrus confusion




| OA | OA valid | OA clouds |
|---|---|---|
| 80,3 | 91,0 | 89,0 |

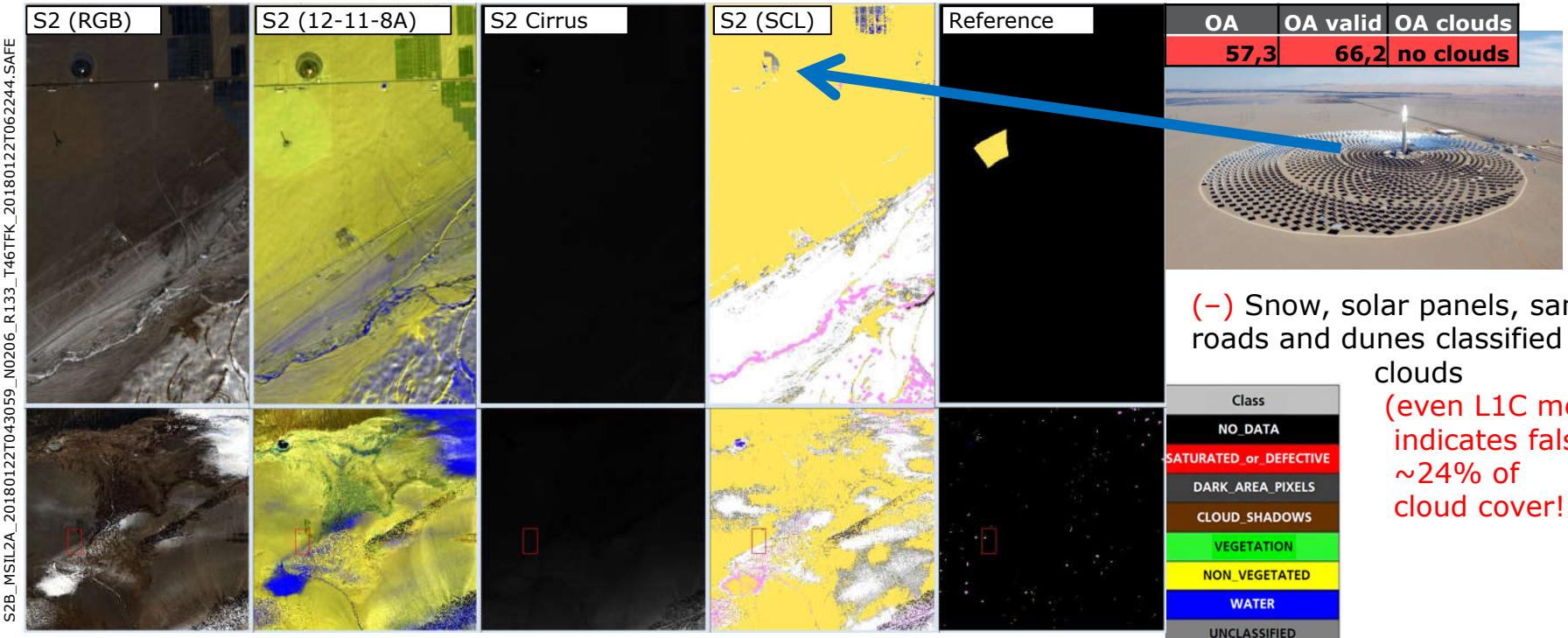
(+) Water, vegetation & non vegetated classified properly

(–) Confusion between cloud classes

| Class |
|---|
| NO_DATA |
| SATURATED_or_DEFECTIVE |
| DARK_AREA_PIXELS |
| CLOUD_SHADOWS |
| VEGETATION |
| NON_VEGETATED |
| WATER |
| UNCLASSIFIED |
| CLOUD_MEDIUM_PROBAB |
| CLOUD_HIGH_PROBAB |
| THIN_CIRRUS |
| SNOW |

# 4. Results/ Example 7: Dunhuang

## – snow, very bright sand, solar panels

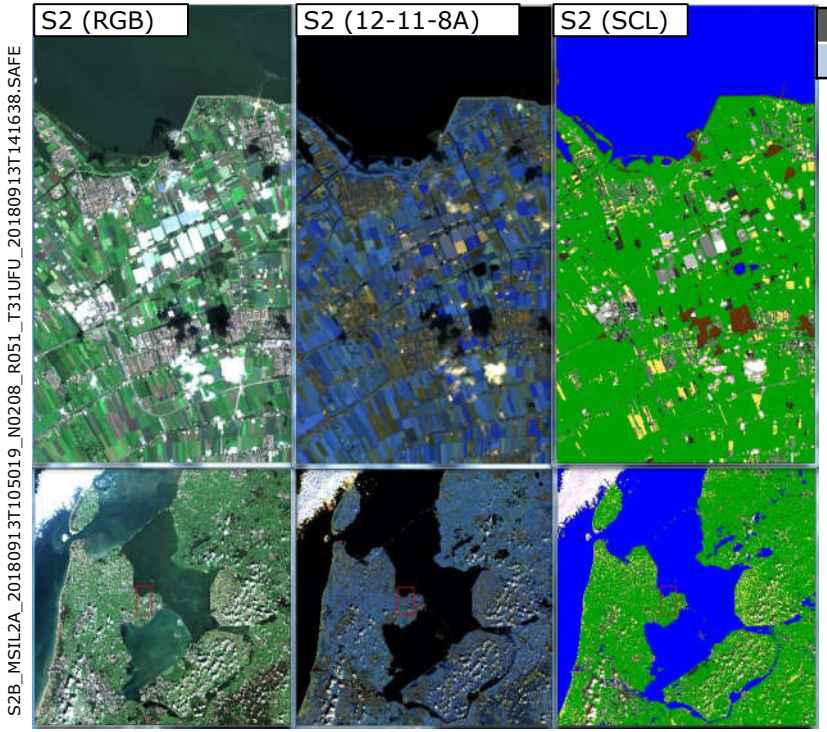



(–) Snow, solar panels, sandy roads and dunes classified as clouds

(even L1C meta indicates false ~24% of cloud cover!!!)

# 4. Results/ Example 8: Amsterdam

## – agriculture, bright and dark urban objects




| OA | OA valid | OA clouds |
|---|---|---|
| 71,1 | 81,5 | 88,7 |

(-) High misclassification rate for bright objects e.g. urban areas, highly reflecting roofs, asparagus fields covered by foil – classified as clouds

(-) High omission and commision errors of medium cloud probability and cirrus classes

– Confusion between cloud classes definitions and some overlapping problems

(-) High omission and commision errors for dark area pixels

– Confusion between cloud shadows, topographic shadows and dark area pixel

– Confusion in the definition of dark area pixel (topographic shadow? also dark soil, burned area?)

# 5. Conclusions

- Very good separation of land, coastal line and water, even if affected by e.g. algae bloom or sediment
- High identification potential for burned areas – even if not a scope of SCL classification
- Averaged overall performance of Sen2Cor 2.5 for 21 products reaches 80,9%
  - Very high accuracy for water, vegetation and snow / ice classes
  - Very low commission error for cloud shadows
  - High misclassification rate for bright objects (urban, arid) – improvement needed, work ongoing
- Good performance for valid pixels (over land and water) and clouds (3 cloud classes) detection:
  - CE and OE of clear pixels separation CE=10,9% and OE=6,9% respectively
  - CE and OE of cloud separation CE=5,6% and OE=16,5% respectively
  - Consolidated cloud mask could provide high quality support for the users applications – work ongoing for forthcoming Sen2Cor processor evolutions
- Sen2Cor processor can be freely downloaded and used http://step.esa.int/main/third-party-plugins-2/sen2cor/
- L2A Product Performance now reported in the L2A Data Quality Report:

https://sentinels.copernicus.eu/documents/247904/685211/Sentinel-2-L2A-Data-Quality-Report

# 6. Outlook

I priority:

- Improvement of SCL over bright surfaces to reduce the number of misclassification on urban area, arid and semi-arid sites towards clouds
- Improvement of SCL for cirrus detection in mountanious areas

} work ongoing

- Development of the Consolidated Cloud Mask (CCM)
- Evaluation o the Cloud Mask Dilation Strategy

II priority:

- Separation of cloud shadows and topographic shadows from other dark features allocated in the dark area class is aimed

- Building a representative independent reference data set is a huge work - validation protocol for L2A to assure validation quality needed.

# Many thanks for your attention

Magdalena Main-Knorn (DLR), Jerome Louis (Telespazio), Bringfried Pflug (DLR),
Vincent Debaecker (Telespazio), Uwe Müller-Wilm (Telespazio Vega),
Valentina Boccia (ESA), Ferran Gascon (ESA), Rosario Quirino Iannone (Rhea spa)

magdalena.main-knorn@dlr.de; www.DLR.de/eoc